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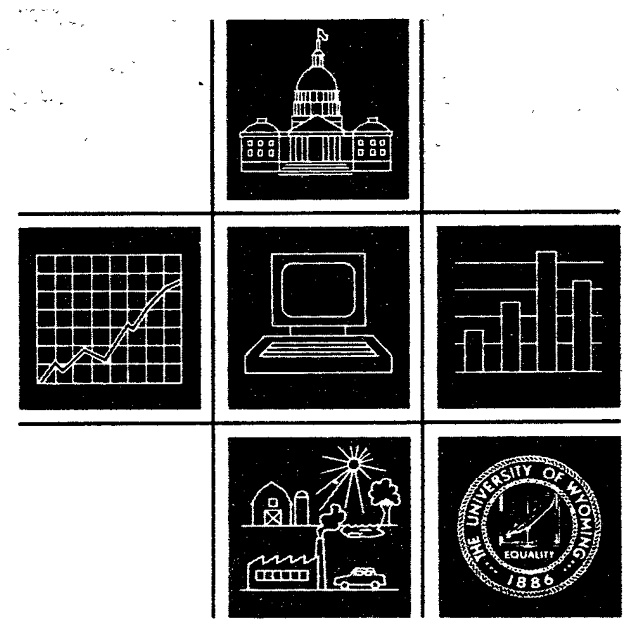

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Volume VI

AN ECONOMIC ANALYSIS OF AIR POLLUTION AND HEALTH: THE CASE OF ST. LOUIS

METHODS DEVELOPMENT IN MEASURING BENEFITS OF ENVIRONMENTAL IMPROVEMENTS

Volume VI

AN ECONOMIC ANALYSIS OF AIR POLLUTION AND HEALTH: THE CASE OF ST. LOUIS

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CHAPTER 1

INTRODUCTION

One of the principle tenets underlying the Clean Air Act and its subsequent amendments is that decreases in air pollution result in reduced human mortality and morbidity rates. Empirical work aimed at demonstrating the existence and strength of this dose-response relationship, however, have produced uneven results. Lave and Seskin (1973, 1977), for example, have reported regression relationships based on aggregate data that show a strong positive association between levels of sulfur dioxide and mortality rates. In contrast, Gerking and Schulze (1981) present an illustration, based on an alternative aggregate data set, indicating that when attention is paid to intervening variables such as medical care, the above conclusion may be reversed. This apparent conflict in results has a number of possible sources including: (1) lack of knowledge concerning the physiological process by which air pollutants affect health and the resulting uncertainties about the choice of covariates used to explain health status as well as the functional form of the relationship, (2) problems in obtaining accurate measurements on the desired variables, (3) multicollinearity between the covariates used, (4) the use of inappropriate statistical methods in estimating the relationships hypothesized, (5) an incomplete understanding of how individuals may alter their consumption patterns in order to defend against possible negative effects of air pollution.

The purpose of this report certainly is not so ambitious as to attempt to "solve" these five problems which have proved to be quite vexing in previous epidemiological investigations. Nevertheless, each of these five problems is addressed at least indirectly in the process of formulating and empirically testing a theoretical health model This model, which adopts an approach similar to that used by Grossman (1972), Cropper (1981), and Rosenzweig and Schultz (1982a, 1982b), and Harrington and Portney (1983) views individuals as producers of health capital in a utility maximizing framework. Hence, the individual is able to adjust his behavior so as to compensate for changes in air quality. Specific adjustments considered involve alterations in the consumption of medical care, exercise, and cigarettes as well as changes in dietary patterns and time spent working. The model also is used to derive a remarkably simple contingent valuation measure of the marginal willingness to pay for improvements in air quality.

The theoretical model is subjected to extensive empirical testing using survey data on adult workers drawn from households in the St. Louis SMSA. Those tests are of interest in one respect because the data used are of high quality, particularly in comparison with their counterparts used in other studies. The health, socioeconomic, and demographic measures are very rich and were collected for the purpose of analyzing the relationship between air pollution and health, rather than for another primary purpose. Additionally, the air pollution measures obtained from the Regional Air Pollution Study (RAPS) are both more detailed and more spatially disaggregated than those available in alternative data sets. Most importantly, however, the empirical results are of interest because they support the hypothesis that reductions in air quality, measured principally as the concentration of ozone at 19 sites in the St. Louis SMSA, negatively affect health. Marginal benefit estimates for various percentage reductions in ozone concentrations are computed based upon these empirical results.

The remainder of this report is divided into five chapters. Chapter 2: (1) reviews the portion of the applied econometric health epidemiology literature that is based on individual observations (microdata) and is concerned with morbidity and (2) describes the methodology typically used to estimate the dollar benefits associated with improvements in air quality. Chapter 3, then, presents in detail the theoretical health model that was briefly described earlier and contrasts the approach taken with the methods discussed in Chapter 2. Chapter 3 also demonstrates how a contingent valuation measure of the marginal willingness to pay for improved air quality can be calculated. Chapter 4 begins the empirical portion of this report by highlighting the key features of both the St. Louis data set and the air quality data drawn from the RAPS and Chapter 5 compares the RAPS data with that from three alternative sources for the St. Louis SMSA in an effort to justify the use of the former. An important by-product of this analysis, is the surprising conclusion that air quality data drawn from RAPS stations frequently are linearly unrelated to corresponding measures obtained from physically adjacent stations in locally operated air monitoring networks. The material presented in the preceding four chapters then is used in Chapter 6 to empirically estimate: (1) the equations of the theoretical model and (2) the marginal willingness to pay for air quality improvements.

Finally, three appendices provide supplementary material. Since this report focuses on the willingness to pay to avoid exposure to ozone and lead, appendices 1 and 2 summarize the controlled experimental and epidemiological results on the human health effects of those pollutants. Appendix 3, reproduces selected portions of a volume by Koontz (1981) which provides documentation for the data base used in the empirical work in the present study. This appendix also explains how a computer tape containing these data may be obtained from the authors.

CHAPTER 2

LITERATURE REVIEW

1. Introduction

During the past several decades, economists have sought to estimate the economic costs associated with the adverse health effects of air pollution. The first step in this estimation has typically been to quantify the relationship between air pollution and human health. Human health is hypothesized to depend on several variables measuring socioeconomic and demographic factors, personal or lifestyle habits, as well as ambient concentrations of atmospheric pollutants and other environmental hazards. By specifying a physical damage or dose-response function describing the relationships between these various factors and human health, the association between air pollution and human health can, at least in principle, be isolated. From this relationship, the change in morbidity or mortality rates resulting from a given alteration in air pollution levels can be computed and an economic value attached. To arrive at this economic value, some measure of direct and indirect costs of illnesses usually is utilized in morbidity studies or, for mortality studies, a measure of the value of life.

This chapter contains a brief and highly selective review of the literature dealing with the benefits to human health resulting from improvements in air quality. Emphasis is placed on empirical studies that use microdata sets to estimate the dollar benefits of improved air quality that arise from reduced morbidity. There are two reasons why this very narrow focus is justifiable in the present setting. First, the purpose in undertaking this review is to assess the methodology and results obtained from data similar to that used in the present study. The St. Louis data set contains cross&sectional measures of the health status of living individuals; there is no information given regarding patterns of mortality. Second, broader surveys of the econometric health epidemiology literature which recently have been conducted by Burness et al. (1983) and Atkinson (1983), are contained in other documents submitted pursuant to USEPA Assistance Agreement CR808893010. The remainder of this chapter is organized into two sections. Section 2 summarizes the approaches taken and results found in several selected studies and Section 3 reviews alternative strategies for computing the benefits of air quality improvements. A brief summary is given in Section 4.

2. The Air Pollution-Health Relationship

As indicated, this section summarizes and critically evaluates selected microdata based studies of the air pollution-health relationship. These studies can be divided into two classifications, depending upon the definition of the health measure used. In the first category, which is comprised of the work by Jaksch and Stoevener (1974), Bhagia and Stoevener (1978), and Seskin (1977, 1979a, 1979b), health (or illness) is measured in terms of contact with the medical system. As a consequence, the results of these studies bear most directly on the question of how alterations in air quality affect short-term or acute illness. The second category of studies, made up of contributions by Crocker et al. (1979), Ostro and Anderson (1981), and Cropper (1981) also focus primarily on acute illness; but examine measures such as days absent from work. Crocker et al. also consider data on disabilities in an attempt to gain in sight into the relationship between air pollution and chronic illness.

A. Air Quality and Medical System Contacts

Jaksch and Stoevener (1974) attempted to quantify in monetary terms the effects of air pollution on the consumption of outpatient medical services. They hypothesized that air pollution can aggravate one's health resulting in increased consumption of medical services for certain respiratory and cardiovascular diseases and any other diseases that may be aggravated by air pollution. Using the Portland, Oregon SMSA as the study area, they obtained their data from several air pollution control agencies, the National Weather Service stations, and the Kaiser Foundation Health Plan.

Their first hypothesis was that deterioration in air quality can increase the consumption of medical services per outpatient contact with the medical system. The model designed to test this hypothesis was specified as follows:

$$I_{ijk} = h(A_{jk}, W_{jk}, S_{ijk}) \tag{1}$$

where I_{ijk} is an index of the dollar value of outpatient medical services consumed for treatment of the ith disease on the jth day for the kth person, A_{jk} represents a measure of air quality (expressed as suspended particulates, micrograms per cubic meter per day) on the jth day for the kth person, W_{jk} is a measurement of meteorological conditions on day j for the kth person, and S_{ijk} represents the socioeconomic-demographic characteristics of the kth person on the jth day of exposure for the ith disease. The index of medical services, though in monetary terms, was designed to reflect the quantity of medical services and not just dollar expenditures which would be influenced by variations in fee charges. Moreover, besides controlling for age, sex, race, and income, the socioeconomic-demographic variables also included measures of smoking, occupational factors, and physical fitness.

The second hypothesis was that deterioration in air quality increases the number of contacts with the medical system per disease category. The model used to test this hypothesis was specified as follows:

$$Y_{icj} = g(A_{cj}, W_{cj}, S_{cj}) \tag{2}$$

where Y_{icj} is computed as the ratio

$$Y_{icj} = \sum_k^K y_{icjk}/N_{cj}, \tag{3}$$

$\sum_k^K Y_{icjk}$ is the summation of the index of consumed outpatient medical services for disease i for all K Kaiser health plan members in census tract c on day j, converted to dollars and N_{cj} is total number of Kaiser respondents residing in census tract c on day j. Also, A_{cj} represents an average measure of ambient air pollution (again expressed as suspended particulates, micrograms per cubic meter) in census tract c on day j, W_{cj} represents an average measure of meteorological conditions in c on day j; and S_{cj} is an average of socioeconomic-demographic characteristics of Kaiser health plan members in c who sought outpatient medical services on day j.

The air pollution exposure data used in this study were obtained from readings on ambient concentrations of suspended particulates available from 18 monitoring stations in the Portland, Oregon area. Although several of these stations were not used in the empirical work performed, location specific exposure levels still could be assigned to individuals, since for each respondent the places of residence and employment were known.

Various forms of these models were estimated using ordinary least squares regression methods. With respect to the first hypothesis, a deterioration in air quality appeared to result in the increased consumption of medical services per outpatient contact for respiratory diseases, but not for circulatory-respiratory diseases. With respect to the second hypothesis, however, variations in air quality did not appear to affect the number of contacts with the medical system per disease category. These results led Jaksch and Stoevener to conclude that economic costs of deteriorating air quality, measured as the frequency and intensity of contacts with the medical system, are positive but not particularly large. Another finding of interest was that there appears to be a time delay between exposure to comparatively high levels of air pollution and contact with the medical system.

Bhagia and Stoevener (1978) followed the Jaksch and Stoevener formulation in a parallel study of the use of medical services in the Portland area. This model was specified as follows:

$$M_{ijk} = f(A_{jk}, W_{jk}, S_k) \tag{4}$$

where M_{ijk} is a dollar index of inpatient medical services (as compared with outpatient services studied by Jaksch and Stoevener) consumed for treatment of the ith disease episode on the jth day for the kth person, A_{jk} is a measure of air quality on the jth day for the kth person, W_{jk} is a measure of meteorological conditions on day j for the kth person, and S_k represents socioeconomic characteristics of the kth person.

Included in the socioeconomic variables were smoking habits, consumption of alcoholic beverages, education, and number of hospital visits in the last three years. Suspended particulates was chosen as the air pollution measure and readings were assigned on the basis of the proximity of monitoring stations to the home and employment locations of respondents. An index of medical costs associated with M_{ijk} was then regressed on all the variables discussed above using least squares metho None of the coefficients on air pollution were statistically significant. Age of the patient, family income, drinking habits, and the number of visits by the patient were significant variables in all the regressions run. Bhagia and Stoevener concluded that given the specification of the model, no relationship between suspended particulates and the consumption of inpatient medical services existed. They feel that this lack of apparent influence of air pollution on health may be due to a distributed lag relationship of greater length than could be analyzed effectively in their data set.

Seskin (1977, 1979a, 1979b) also examined data that were similar to those used by Jaksch and Stoevener (1974). In particular, Seskin drew a sample from members of the Group Health Association in the Washington, D.C. metropolitan area in an effort to uncover a connection between their use of outpatient medical services and day to day variations in air quality levels. Although this study began with data on individual health plan members, all of the empirical work reported focused on aggregates of those observational units. The time series model examined was:

$$V_i = V_i(AP, W, D) \qquad (5)$$

where V_i denotes the number of unscheduled visits per day over the period 1973-74 to department i in one of the Association's medical centers; i = urgent visit (from which patients often are referred to another department), internal medicine, pediatric, optometry and opthalmology; AP denotes air quality, W denotes meteorological conditions, and D denotes dummy variables for Saturday and Sunday. Air quality was measured as the maximum one hour average oxidant reading taken from one station in downtown Washington, D.C. for each day in the time period considered. Because Seskin examined only the time series variation in the data and ignored the cross-sectional variation, personal, socioeconomic, and demographic characteristics of the study population were thought to be unimportant.

The only air pollution-morbidity incidence relationship which Seskin found to be significant in both years 1973 and 1974 was that between daily unscheduled visits to the ophthalmology department and oxidant levels. The best results were obtained when the oxidant measure included in the equation was contemporaneous with the visit data. Lagged relationships between visits end air quality, episodic effects created by poor air quality lasting for several days, and synergistic effects between oxidants and NO_2, SO_2, and CO also were examined; but without much success in detecting consistently significant relationships. These results support the contention that apart from comparatively minor effects such as eye irritation, short-term or acute ill health is largely unrelated to the mobile source emissions which are primarily responsible for ambient oxidant concentrations. However, the aggregate nature of the observational units used easily could have masked potentially important relationships between air quality and unscheduled visits by special populations of individuals such as asthmatics or the elderly. The use of readings from only one monitoring station to represent oxidant exposure levels for all sample members in the Washington, D.C. area may also have been a problem; although as Seskin indicated, levels reported from other stations did not differ greatly from those used.

B. Air Pollution, Work Loss Days, and Disability

Crocker et al. (1979) used a detailed, highly disaggregated data set gathered from interviews conducted by the University of Michigan Survey Research Center's Panel Study in Income Dynamics (PSID) from 1968 through 1976 to analyze acute and chronic illness attributed to air pollution. The independent variables used in their model can be divided into biological and social endowment variables (age, education, income, race, etc.), life-style variables (exercise and smoking habits, food expenditures, etc.), pecuniary variables (medical insurance, savings, the wage rate, etc.) and environmental variables (air pollution, weather, occupational exposure). Two dependent variables were employed: (1) work days lost due to illness, and (2) whether the respondent had a disability limiting the type or amount of work that could be performed. The former variable was thought to measure incidence of acute illness and the latter was thought to measure chronic illness. Observations on each of these variables pertained to household heads; consequently, the focus of this study was on the health of adults.

The air quality data used in this study measured the concentration of five pollutants: (1) nitrogen dioxide, (2) ozone, (3) total oxidants, (4) total suspended particulate, and (5) sulfur dioxide. Annual geometric means as well as 30th and 90th percentile values for each pollutant were obtained. However, for the ozone and total oxidant data, the number of monitoring stations and the monitoring time intervals allowed for only minor variations in exposure levels between individuals. As a result, the empirical estimates reported do not consider these two pollutants.

A potentially serious difficulty with the data set arose because the air pollution data had to be matched with the measurements on the household heads for the PSID data. Only the county of residence for each of those individuals was known. For some counties, no air quality data were available, while for other counties data were available from two or more monitoring stations. To circumvent this problem, individuals who did not live in a county where air quality data were available were dropped from consideration, thus reducing the sample size by 40-50 percent. Individuals living in counties with multiple monitoring stations were assigned the readings from the single station that had operated for the greatest proportion of the period 1968-1976. That strategy, which probably resulted in a tendency to assign downtown pollution measures for all who lived in a county, may have represented an important source of measurement error since there frequently are substantial variations in air quality between location, particularly in larger counties. Moreover, the current year air quality measures assigned may not be indicative of the long term exposures that individuals have faced.

Using this data set, Crocker et al. estimated several dose-response functions for both acute and chronic illness. All equations were estimated by ordinary least squares. Although the researchers took care to assure that only those variables that are outside a household's control or had been established prior to the period being considered were included as regressors, they admitted that some of the variables (cigarette consumption, exercise, and dietary habits) could be adapted quickly to changing circumstances. However, they argue that these habits are insensitive to changing circumstances and are likely to persist. In any event, most of the regressions run had statistically significant coefficients on the air pollution measures employed. More specifically, in each of the seven different unpartitioned samples used to estimate acute illness dose-response functions, significant and correctly signed air pollution coefficients were present.[1] Additionally, significant and correctly signed coefficients of air pollution occurred 9 9 of 12 regressions run where the chronic illness measure was used as the dependent variable. On the basis of these results, Crocker et al. concluded that air quality, in addition to other factors, play a significant role in determining patterns of both acute and chronic illness.[2]

Ostro and Anderson (1982) performed an analysis of data from the 1976 Health Interview Survey (HIS) conducted by the National Center for Health Statistics. Similar to the work of Crocker et al., these authors used days absent from work as the health measure to be explained; however, the sample of individuals considered was drawn more restrictively. Ostro and Anderson included only nonsmoking males in their data set in order to reduce the possibility that: (1) the negative health effects of air pollution would be confounded with those of cigarette smoking and (2) the work loss days observed may have occurred for non-health reasons. In any case, work loss days were hypothesized to be a function of various demographic and socioeconomic variables, the existence of chronic disease, climate conditions, measures of "urbanness," in addition to air quality. Two air quality variables actually were employed, total suspended particulates and sulfates. The estimated relationship was specified in linear form and estimated alternatively by ordinary least squares and limited dependent variable methods (Tobit and logit).

As the authors indicated, the results obtained from their estimated equations generally were consistent with a priori expectations. Air pollution, as measured by total suspended particulates, frequently was positively and significantly (at the 5 percent level) related to the incidence of work loss days (WLD). Interestingly, however, particulate readings did not appear to influence the number of days lost given that a WLD episode has occurred. The coefficient of the sulfate variable, on the other hand, never was positive or significantly related to WLD. This poor performance was blamed, at least partially, on measurement errors in the data. Unfortunately, Ostro and Anderson do not discuss in any depth the important issue of how air pollution readings were assigned to the individual sample members. The assignment methodology, as has been indicated previously, also could have influenced the performance of the pollution variables.

The work of Cropper in explaining cross-sectional variations in the incidence of work loss days represents a refreshing change from the approaches taken in the five studies just reviewed. In those five studies, the main focus was on estimating damage or dose-response functions in an effort to identify the health-air pollution relationship. A key assumption underlying this approach is that individuals are unaware of the health effects of air pollution and, as a consequence, do not take them into account in making decisions (Lave, 1972, and Lave and Seskin, 1977). That view has been disputed by many health economists (see, for example, Grossman, 19721, 1972b, 1976) who instead have hypothesized that individuals do indeed take defensive action against ill health. More specifically, this action is assumed to be taken in a utility maximization framework in which diet, exercise, and medical services are but a subset of the available consumption goods. Cropper's model adopts this perspective; however, a detailed description of that model is not presented here for two reasons: (1) the main focus of this section is on summarizing empirical results and (2) a similar model is presented in Chapter 3.

In any case, Cropper's theoretical analysis leads to the following statistical formulation of the equation to be estimated as a Tobit model

$$\begin{aligned} \ell n\ TL_{it} &= \text{undefined} && \text{if} \quad X_{it}^{T}\beta + U_{it} \leq 0 \\ \ell n\ TL_{it} &= X_{it}^{T}\beta + U_{it} && \text{if} \quad X_{it}^{T}\beta + U_{it} > 0 \end{aligned} \qquad (5)$$

where TL_{it} denotes time lost from work by the i^{th} individual in year t, X_{it}^{T} is a row vector of observations on individual i in year t measuring characteristics including factors affecting investment in health (education, marital status, presence of a chronic condition), the wage rate, and variables affecting the rate of decay in the health stock (stress, race, air pollution exposures), β is a vector of coefficients, and U_{it} is a random disturbance term. Cropper obtained health related data from the Michigan Survey Panel Study in Income Dynamics which were then matched with county level observations on air quality, measured as the natural logarithm of the annual geometric mean SO_2 reading. Thus, Cropper's data set bears similarity to that used in the Crocker et al. study.

Cropper reports three almost identically specified regression equations for the PSID interview years of 1970, 1974, and 1976. In each of those regressions, the sign of the coefficient of the air pollution variable was positive and barely significantly different from zero using conventional tests. The ratio of the estimated coefficients to their standard errors were in the range of 1.38 to 1.52. These results corroborate epidemiological studies in which exposure to sulfur dioxide has been linked to acute illness (which in turn would be linked to work loss days). However, additional pollutants were not explicitly considered since collinearity between them produced insignificant coefficients. The SO_2 variable was therefore regarded as an index of all air pollution exposures found.

3. Benefit Estimation

As indicated previously, the main purpose of the six studies reviewed in the previous section was to quantify the dollar benefits of air quality improvements using the estimated air pollution health relationships. This section provides an overview of the procedures used in those studies, as well as in others, in order to assess the benefits or reduced morbidity. The overview presented again will be selective. Burness et al. provide a somewhat broader evaluation of benefit assessment methods which examines both morbidity and mortality.

The most common method of estimating the benefits of reduced morbidity involves computing the costs of air pollution induced illness. Jaksch and Stoevener and Bhagia and Stoevener, for example, attempted to estimate these costs directly by defining the dependent variables in their regression equations as indices of the dollar value of medical services consumed. In other words, their regression equations showed the extent to which medical expenses might be expected to fall in the face of an improvement in air quality. Nevertheless, neither Jaksch and Stoevener nor Bhagia and Stoevener made explicit benefit calculations.

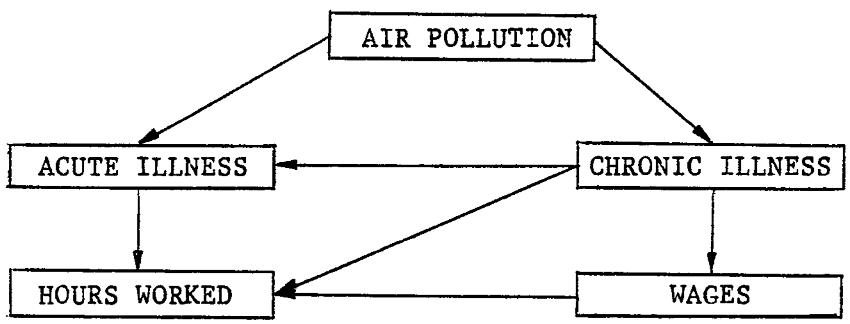
Seskin, on the other hand, did report explicit benefit calculations in his study of the association between unscheduled visits to a medical care facility and ambient concentrations of photochemical oxidants. Because only visits due to an ophthalmologic reason were found to be significantly associated with the level of oxidants, only benefits pertaining to this relationship were calculated. From the estimated damage function, Seskin determined that a 10 percent reduction in the level of photochemical oxidants would bring a decrease of 1.1 percent in 1973 and 4.3 percent in 1974 of unscheduled ophthalmologic visits. He then determined that in order for Washington, D.C., oxidant levels to comply with the 1971-1978 national standard for these pollutants, oxidant levels would have to have been reduced 55.6 percent in 1973 and 42.9 percent in 1974. These estimates were then applied to the oxidant-opthalmology elasticities derived from the damage function. Assuming linearity, this calculation indicated that reductions in oxidant levels to meet national standards would produce a 6.1 percent reduction in unscheduled opthalmologic visits during 1973 and an 18.4 percent reduction during 1974. These figures represent approximately 136 unscheduled visits in 1973 and 367 in 1974.

The next step was to attach monetary values to these visits. Using a value representing average medical costs associated with visits for simple eye problems in Maryland, the direct medical costs were calculated to be $20 per visit or approximately $2700 in 1973 and $7300 in 1974. Using data tabulated by Cooper and Rice (1976) which showed that indirect morbidity costs of diseases of the central nervous system and sense organs to be 66.3 percent as great as direct medical costs, Seskin calculated indirect costs of these visits to be $1790 for 1973 and $4840 for 1974. Summing direct and indirect medical costs gives the benefits accruing to Group Health Association members of $4490 in 1973 and $12,140 in 1974. Assuming that those members are representative of the resident population of the Washington, D.C. area, total benefits can be calculated by multiplying this figure by the ratio that population bears to the number of Group Health Association members (20:1). Thus, the 1973 total benefit estimates would be $89,800 for 1973 and $242,800 in 1974.

Crocker et al. took an alternative approach to assessing the benefits of reduced morbidity associated with an improvement in air quality. They incorporated their previously discussed acute and chronic illness dose-response equations into a larger system that also determined an individual's wage and hours of work. Figure 1 provides a schematic illustration of the empirical model employed. As shown, increases in air pollution are hypothesized

Figure 1

Effect of Air Pollution on Labor Productivity



to increase both acute and chronic illness, and those illnesses, in turn, force reductions in hours worked as well as in the wage received, To implement this model, Crocker et al. estimated a system of four recursive equations using a sample drawn from the 1969, 1970 and 1971 University of Michigan Survey Research interview data. The four equations consisted of expressions for chronic illness, acute illness, the wage an individual receives, and the labor supply. From this system of equations, estimates of the direct and indirect effects upon the labor supply, measured in annual hours worked, of air pollution induced acute and/or chronic illness were calculated according to the following expression:

$$\frac{\Delta(\text{WORK HOURS}\cdot\text{WAGE})}{\Delta(\text{AIR POLLUTION})} = \frac{\Delta(\text{WORK HOURS})}{\Delta(\text{AIR POLLUTION})}\cdot\text{WAGE} + \frac{\Delta(\text{WAGE})}{\Delta(\text{AIR POLLUTION})}\cdot(\text{WORK HOURS}) \tag{6}$$

Using the equations estimated with the 1970 PSID data, they found that a 60 percent reduction in air pollution nationally would result in a per capita labor productivity gain of $288 (in 1978 $).

Unfortunately, neither the Seskin study nor the Crocker et al. study offers a persuasive theoretical rationale justifying the approach taken to compute estimated benefits. As indicated above, Seskin focuses on the savings on medical expenses resulting from reductions in air pollution, while Crocker et al. examine increased labor productivity. These measures, however, may not accurately reflect what individuals are willing to pay for improved air quality. In particular, in the absence of an explicit choice model, it is difficult to see: (1) why individuals would choose to value air quality changes in terms of either of these media,[2] or (2) how the benefits computed relate to an explicit welfare measure. In regard to this second point, a widely used and intuitively appealing welfare measure involves calculating the maximum amount that an individual would be willing to pay for an improvement in air quality subject to the constraint that his utility level must remain unchanged. While other measurements of welfare change certainly could be used, the studies cited make little effort to determine the extent to which an individual ends up better off when air quality improves.

In fact, Cropper is apparently the only investigator to have calculated the willingness to pay for improved health using methods derived from a theoretical model of consumer choice. However, she adopts the assumption that health is a pure investment good. That is, good health produces no direct utility; it only serves to reduce time lost from work, thereby augmenting the capacity to earn income. In this case, the decision to invest in health can be separated from the decision to produce other goods and a health investment point is chosen so as to maximize the present value of full income (R) net of the cost of investment. Utility then is maximized subject to a given level of R. Because of the separability between the decisions to invest in health and to consume other goods, and since air quality (A) has no direct effect on the individual's utility level, the maximum willingness to pay for a small percentage rise in A is $(dR/dA)\cdot(A)$. In other words, this framework predicts that an individual would, at most, be willing to give up his net income increase occasioned by reduced sick time when air quality improves. This result would appear to lend at least partial support to the general approaches used by Crocker et al. and also Ostro and Anderson where the income foregone due to air pollution induced illness was of primary concern.

4. Summary

This chapter has directed attention to a key problem in the econometric air pollution-health epidemiology literature. In five of the six studies reviewed, neither the health expressions estimated nor the benefit calculations made were based on an explicit theoretical model. As a consequence, although the findings reported are interesting, they are difficult to apply in a policy setting. In fact, the lack of a sound theoretical approach may have at least partially led to the wide variations in estimated impact of air pollution on health noted by Burness et al. Additionally, the benefit estimates reported by Seskin and Crocker et al. do not correspond to a precise measure of welfare change. The sixth study, conducted by Cropper represents a substantial improvement over this situation, as her benefit estimates were constructed on the basis of a theoretical health model first proposed by Grossman (1972). Her model justifies the use of net income changes induced by the positive effect of air quality on health as a benefit measure. Thus, her approach also lends some support to the Crocker et al. and Ostro and Anderson studies, which focused on the work loss days as a measure of the impacts of air pollution.

The chapter to follow generalizes a version of the Cropper model in order to treat health as a consumption good as well as an investment good. That is, in the model presented, individuals are assumed to derive direct utility from good health as well as increased levels of income. As demonstrated there, that alteration in the model also implies a change in the method used to compute willingness to pay for air quality.

FOOTNOTES

1. Other regressions were run where the sample was partitioned according to income, smoking habits, and severity of disability.

2. Crocker et al. does present an explicit model which has similarities to the work of Grossman (1972); however, that model was not employed in the benefit estimation exercise.

CHAPTER 3

A SIMPLE HEALTH MODEL

1. Introduction

The model to be developed in this chapter, as indicated previously, represents a generalization in one respect of the approach taken by Cropper (1981). Health is treated as a consumption good from which an individual derives direct utility as well as an investment good which contributes to increased income. Decision-making, however, is examined by focusing on only one time period rather than on the multiperiod framework used by Cropper (1981) and Grossman (1972a, 1972b, 1976). The model, which is presented in Section 2, has strong parallels with the work of Rosenzweig and Schultz (1982a, 1982b) and Harrington and Portney (1983). The purpose of the Rosenzweig and Schultz papers was to analyze how the behavior of expectant mothers affects the birthweight of their children. The objective of this chapter, on the other hand, which is similar to that purused by Harrington and Portney, is to determine how to calculate the maximum dollar amount that an adult worker would bid in order to obtain an improvement in air quality levels. Methodology for computing that bid is considered in Section 3.

2. The Model

In the model to be applied, as shown in equation (1), individuals derive utility from the consumption of two classes of goods: (1) their own stock of health capital (H) and (2) goods that yield direct satisfaction, but do not affect health (X).

$$U = U(X, H) \qquad (1)$$

Thus; apart from its one period focus, the utility function in equation (1) is quite similar to that used by Grossman in his treatments of the consumption aspects of health. In contrast, Rosenzweig and Schultz use a somewhat more complete specification of the utility function by including a good, Y, which yields direct satisfaction and also affects health. As a consequence, the model proposed by those authors is able to explain behavior such as smoking, dietary patterns, alcohol consumption, and exercise. The added richness resulting from incorporating the Y good is not pursued here, however, since the expression giving the willingness to pay for improved air quality would be unaffected. Two other possible refinements in the model would be to: (1) replace the health stock variable in the utility function with the flow of services it generates and (2) allow for home production of the

X-commodity. Both of these features are reflected in the Grossman (1972a) modeland the first is reflects in the Herrington and Portney analysis. However, they are not adopted here since no substantive alteration in the analysis would result.

The health stock is treated in this model as an endogenous variable, whose value is determined by the production function

$$H = H(M; \alpha) \tag{2}$$

where M denotes medical care (from which the individual derives no <u>direct</u> utility),, α denotes a set of exogenous variables, such as air quality, that affect the efficiency with which an individual can produce H using a given level of M, $H_M > 0$, and $H_\alpha > 0$.

Utility then is maximized subject to equation (2) as well as the money and time constraints shown in equations (3), (4), and (5)

$$XP_X + MP_M = I \tag{3}$$

$$XT_X + MT_M + T_W + T_L = T \tag{4}$$

$$WT_W = I \tag{5}$$

In the above equations P_i denotes the money price of commodity i (i = X, M), I denotes money income, T_i denotes the time required to consume one unit of commodity i (i = X, M), T_W denotes time spent working , and T_L denotes time lost from market and non-market activities due to illness. T_L, in turn, is related to the health stock according to

$$T_L = G(H) \tag{6}$$

where $G_H < 0$ and $G_{HH} > 0$ reflecting the assumption that an improvement in health reduces time lost from market and non-market activities, but at a decreasing rate. Equations (3), (4), (5), and (6) easily can be combined into the "full income" budget constraint shown in equation (7)

$$Xq_X + Mq_M + WG(H) = WT \tag{7}$$

where $q_i = (P_i + WT_i)$, i = X, M.

The approach adopted in this model stands in contrast to the dose-response or damage function approach that is widely used in the econometric health epidemiology literature. In the model described above, the consumer determines the amounts of goods and services to consume by examining all relevant exogenous information including full prices (the q_i), the wage rate paid for his labor services, and the air quality levels faced. In other words, health is treated as just one good in the model. Moreover, the health stock is produced using another consumption good as an input, namely M. As a consequence, the model illustrates that by regressing measures of morbidity on variables such as the consumption of medical care in addition to air quality levels, previous investigators may have been regressing one choice variable on others.[1] Since single equation estination methods have been used almost exclusively, simultaneous equation bias easily could have been a significant problem in measuring the effect of air quality changes on health. In summary, therefore, any estimate of the health production function should account for the fact that it is embedded in a larger set of optimization equations.

The model just specified can be analyzed further by examining: (1) the first order conditions for a constrained utility maximum and (2) certain comparative statics results. The choice problem confronting the individual is to maximize equation (1) subject to equations (2) and (7). Formally, this problem can be re-expressed by substituting the health production function, equation (2) into both (1) and (7) and then writing the Lagrangian

$$L = U(X,\ H(M;\ \alpha)) - \lambda(Xq_X + Mq_M + WG(H(M;\ \alpha)) - WT) \tag{8}$$

First order conditions for a maximum are

$$\frac{\partial L}{\partial X} = U_X - q_X\lambda = 0 \tag{9}$$

$$\frac{\partial L}{\partial M} = U_H H_M - \lambda(q_M + WG_H H_M) = 0 \tag{10}$$

$$\frac{\partial L}{\partial \lambda} = WT - Xq_X - Mq_M - WG(H(M;\ \alpha)) = 0 \tag{11}$$

As these equations show, the utility maximizing individual will equate the ratio of marginal utilities of the goods consumed to the corresponding ratio of prices. An interesting aspect of this calculation, as noted by Rosenzweig and Schultz (1982a), is that the individual derives utility from the consumption medical care, M, <u>only</u> indirectly through its effect on health. Additionally, the price term shown in equations (10) account for not only the full, time inclusive, costs of M; but also the effect its consumption has on the time available for market and non-market activities ($T - T_L$). As shown, an incremental change in available “healthy" time is valued at the individual's wage rate.

The comparative static properties of the model also are of interest. More specifically, the effects of an alteration in air quality on the. consumption of X and M can be expressed as weighted averages of pure price and income changes as shown in equations (12) and (13)

$$\partial X/\partial\alpha = C_X(\partial X/\partial q_X) + C_M(\partial X/\partial q_M) - G_H H_\alpha(\partial X/\partial T) \tag{12}$$

$$\partial M/\partial\alpha = C_X(\partial M/\partial q_X) + C_M(\partial M/\partial q_M) - G_H H_\alpha(\partial M/\partial T) \tag{13}$$

In these equations

$$C_X = -\lambda^{-1} U_{XH} H_\alpha \tag{14}$$

$$C_M = -\lambda^{-1}(U_{HH} - \lambda W G_{HH}) H_M H_\alpha \quad (15)$$

use is made of the simplifying assumption that $H_{M\alpha} = 0$, and the price effects shown reflect pure substitution in the sense that they ignore any associated income effects. Furthermore, if $U_{XH} > 0$, then $C_X < 0$ and if $U_{HH} < 0$, then $C_M > 0$. Therefore: (1) since $\partial X/\partial q_X < 0$, $\partial X/\partial q_M > 0$, and if $\partial M/\partial T > 0$, an improvement in air quality leads unambiguously to an increase in the consumption of the X-good and (2) since $\partial M/\partial q > 0$, $\partial M/\partial q < 0$, and if $\partial M/\partial T > 0$, that same improvement in air quality is "likely" to lead to a decrease in consumption of medical services. In other words, the consumption of medical services would fall if the pure substitution effects reflected in the first two terms of equation (13) are larger in absolute value than the pure income effect captured by the third term.

Intuitively, then, an improvement in air quality has two effects. First, ignoring income effects, it operates in exactly the same way as a wedge driven between q_M and q_X. That is, an increase in a is equivalent to an increase in the ratio q_M/q_X which would encourage consumption of X and discourage consumption of M. Second, the improvement in air quality has an income effect which results from the associated increase in time available for market and non-market activities. That positive income effect would encourage the consumption of both goods. Hence, consumption of X must rise and consumption of M falls if pure substitution effects dominate the income effect.

This situation, where changes in air quality have both substitution and income effects, contrasts with the implications of the model specified by Cropper. As indicated in Chapter 2, the only effect of health on utility in the Cropper model is through the budget constraint. Hence, the decision to invest in health can be separated from the decisions to purchase other goods. This distinction has a direct bearing on the appropriate method for estimating the willingness to pay for air quality. In the Cropper model, the willingness to pay estimate was derived via a simple manipulation of the budget constraint, whereas in the model presented here, the entire equation set must be utilized.

3. Calculating the Marginal Willingness to Pay

In this section, the marginal willingness to pay for air quality is derived from the model previously presented using the method of compensating variations (CV). This approach to calculating the marginal willingness to pay is chosen because it explicitly holds the individual's utility level constant in determining how much money an individual would give up in order to consume at a new price set. The method of equivalent variation (EV), which asks what an individual would willingly give up in order to forego consuming at the new price set, also would hold utility constant. However, since there may be only a minor difference in the numerical values of the bids produced by the two methods, the choice between them may not be important (Freeman, 1979). Moreover, note that either method would be appropriate because, as demonstrated in Section 2, the comparative static changes in X, and M given an alteration in air quality all can be re-expressed as weighted averages of pure substitution effects and income changes.

Before deriving the expression for the CV marginal willingness to pay for air quality, a minor adjustment must be made to the model. In particular, the budget constraint is respecified as

$$Xq_X + Mq_M + B - W(T - G(H)) = 0 \tag{16}$$

where B denotes the bid, or amount paid, for air quality. Equation (16), then, requires that the individual actually must spend part of his full income, WT, to obtain an improvement in air quality. As a consequence, the individual's maximum willingness to pay for an incremental change in air quality would be found by computing **$dB/d\alpha$ while:** (1) holding utility constant and (2) ensuring that the individual's equilibrium conditions are obeyed.

One way to find a suitable expression for **$dB/d\alpha$ is to totally** differentiate both the utility function (equation (1)) and the health production function (equation (2)), substitute the latter into the former, and set $dU = 0$, in order to obtain

$$0 = U_X dX + U_H H_M dM + U_H H_\alpha d\alpha \tag{17}$$

Next, totally differentiate the budget constraint, as shown in equation (18), holding $dq_i = dW = dT = 0$ for i = X and M.

$$0 = q_X dX + (q_M + WG_M H_M) dM + dB + WG_H H_\alpha d\alpha \tag{18}$$

Equation (17) can be solved for dX, rewritten using the first order equations as

$$dX = -((q_M + WG_M H_M)/q_X) dM - (U_H H_\alpha / U_X) d\alpha \tag{19}$$

and then substituted into equation (18). After rearranging terms, those operations yield:

$$dB/d\alpha = [(U_H q_X / U_X) - WG_H] H_\alpha \tag{20}$$

which can be further simplified using the first order equations (9) and (10) as shown in equation (21)

$$dB/d\alpha = H_\alpha q_M / H_M \tag{21}$$

Note that this expression for estimating the marginal willingness to pay for air quality is relatively straightforward to implement empirically, since the utility terms have been eliminated. Additionally, this **expression for $dB/d\alpha$** would be unaltered if the Y good were appropriately introduced into the utility function, the health production function, and the budget restraint. Hence, that expression is robust in the face of at least some alterations in model specification.

Equation (21) suggests that the individual would be willing to pay more for a given air quality improvement, the greater the associated improvement in health. Also, the bid would be higher, the lower the productivity of medical services and the higher their cost. As a consequence, if medical services are an expensive and ineffective means of producing good health, then quite naturally, the individual would be willing to pay more for air quality improvements. In that situation, air quality improvements simply become a more attractive mechanism through which to augment the health stock.

The marginal air quality bid shown in equation (21) easily can be compared to the bid that would result if health was treated as a pure investment commodity; i.e., if H was eliminated from the utility function. In that event, the first term in brackets in equation (20) would equal zero and this alternate marginal bid $dB'/d\alpha$ would be calculated according to

$$dB'/d\alpha = - WG_H H_\alpha \tag{22}$$

which simply values the reduction in time lost from market and non-market activities caused by the improvement in air quality at the wage rate. This bid is remarkably similar to the damage function approach used by Lave and Seskin (1977) to estimate the gains from reducing air pollution induced illness. Those authors obtained their benefit estimates by adding the value of the decrease in lost work time to the decrease in required medical services. The bid in equation (22) ignores any changes in medical expenses; however for minor illnesses these are likely to be small. In that case, therefore, the CV benefit estimate (based on the situation where health is treated as a pure investment good) and its counterpart using the damage function approach would be very similar. Note, however, that the willingness to pay estimate from equation (21) exceeds the one from equation (22) by the amount shown in equation (23)

$$(dB/d\alpha) - (dB'/d\alpha) = (q_M + WG_H H_M)(H_\alpha/H_M) > 0 \tag{23}$$

which is positive in light of the first order equation (10). That result should be expected since the model analyzed in this chapter treats health as a commodity with both consumption and investment attributes.

4. Conclusions

This chapter has developed a health oriented choice theoretic framework for the purpose of determining an individual's marginal willingness to pay for improved air quality. The willingness to pay expression, which was derived using the compensating variation approach, is quite simple in that it involves only one price (that of medical care) and two partial derivatives from the health production function (those for air pollution and medical care). Moreover, the willingness to pay expression does not involve any utility terms so that empirical estimation of it appears to be relatively straightforward. Chapter 4, which follows, begins the empirical portion of this report by describing the St. Louis health and air quality data used in making the willingness to pay estimates. Those estimates themselves are presented in Chapter 6.

FOOTNOTES

1. If the Y good were explicitly included, the model also would illustrate the general problem of regressing a morbidity measure on variables reflecting cigarette and alcohol consumption, exercise patterns, or dietary habits.

2. Another method of deriving $dB/d\alpha$ would make use of an indirect utility function. That procedure is used by Harrington and Portney to obtain a result that is similar to the one presented here. In fact, the two results would be identical if Harrington and Portney had defined their D variable as units of a good rather than the dollar amount of defensive expenditures. If D were defined in units, then the price per unit would appear in their equation (17) (compare with equation (21) below in this report).

CHAPTER 4

THE ST. LOUIS HEALTH AND AIR QUALITY DATA

1. Introduction

The preceding chapters developed a framework for the methodology to be used in the empirical estimation of benefits accruing to individuals from improvements in air quality. The remainder of this report deals with the application of this framework to the St. Louis pollution-morbidity data set, the collection of which was supported by the USEPA. This chapter is organized into three additional sections. Section 2 provides an overview of the St. Louis health data and Section 3 discusses the air quality data used. A brief conclusion is contained in Section 4.

2. The St. Louis Health Data Set

A. Background

In April, 1974, the Environmental Protection Agency (EPA) awarded a contract to Geomet, Inc. (now a subsidiary of Geomet Technologies, Inc. [GTI]) to perform a household interview survey of the St. Louis SMSA. The survey was designed to gather data relevant for quantifying morbidity costs. Furthermore, it was to be administered during the years 1975-1977 in an effort to take advantage of comprehensive air quality data gathered from a network of 25 monitoring stations throughout the St. Louis SMSA which were operated in connection with the Regional Air Pollution Study (RAP). However, final clearance of the questionnaire was not obtained from the Office of Management and Budget (OMB) until January, 1978. By this time, the RAPS network was no longer in operation.

In any case, the questionnaire was administered over the period June 1978-July 1979. Households were enrolled in the survey on a weekly basis at the rate of 80 per week for the 52 weeks. The households selected for the survey were systematically allocated over the 52 weeks so that at any point in time the study sample would still represent the whole. Each household was asked to participate in the survey for eight weeks. A background interview was administered at the beginning of the eight weeks followed by four biweekly follow-up interviews. Later, a follow-up interview designed to collect supplemental data was conducted to complete the data base. Of the 4160 solicited households, 3063 or 73.63 percent participated in the basic survey to completion. Eighty-five percent of those households provided supplemental information. This represents 62.36 percent of the 4160 households originally selected to participate.

Three forms originally were utilized to gather health, socioeconomic, and demographic data from each household: a "Household Background Questionnaire," and "Individual Background Interview," and a "Telephone Interview Form." The first two instruments were to be completed during the initial interview with each participating household. The third instrument was administered during each of the four biweekly follow-up periods. The Household Background Questionnaire was designed to identify all members of the household and their basic demographic characteristics. The demographic characteristics included age, race, sex, and education. In addition, in order to ascertain the socioeconomic status of the household, a categorical question was asked regarding the income of the entire household. Information on the medical insurance of each member of the household also was gathered.

A major purpose of the Individual Background Interview was primarily to establish health status. Any pre-existing chronic conditions that were reported by the respondents were recorded according to a detailed code developed by Schneider, Appleton, and McLemrie (1979) in their paper entitled "A Reason for Visit Classification for Ambulatory Care." Other questions concerning the subjective appraisal of each individual's health status and the number of contacts with the medical care system also were posed in order to measure baseline health levels. The remainder of the Individual Background Interview dealt with identifying each individual's regular activity patterns. An individual's major activity and the occurrence of this activity were obtained to determine the typical location, days, and hours away from the home. Individuals who worked either part or full time were asked for information on the nature of their job. Also included in this survey were questions concerning: (1) commuting routines associated with the major activity and other various activities, (2) commuting and waiting times associated with doctor visits, and (3) smoking habits of each individual who was 14 years or older. The extent and duration of cigarette smoking as well as cigar and pipe smoking, was obtained for each individual who was smoking at the time of the survey.

At the conclusion of both background interviews the respondents were asked to participate in the eight week follow-up survey. Respondents who agreed to take part in this survey provided daily diary type information on how their health or other events altered their normal routine. These data, provided via the Telephone Interview Form, were intended for use in determining the relationship between air pollution and acute illness. The information obtained dealt with the following health related areas:

1) Activity restrictions

   Any activity restriction was categorized according to its degree of restriction, i.e., days confined to a hospital, to a nursing home, to bed, to the home or simply a reduction in usual activities.

2) Absenteeism

   The days of work and/or school absenteeism were recorded for each follow-up period.

3) Physician contacts

Physician contacts were categorized according to the means by which the contact took place, i.e., a visit to the doctor's office, a visit to the outpatient service in a hospital, etc.

4) Receipt of Ancillary Services

This question concerned whether shots, x-rays, or lab tests were required when a physician's care was sought. Prescriptions filled also were recorded.

The reasons associated with these health events were categorized and recorded in the same manner for the chronic illness data. Also provided by the respondents were changes in the normal routines of each individual. Included was information on changes in job status, days out of town, and days at home for vacation from work or school.

The EPA decided after the basic survey was completed to collect supplemental data to enhance the analytic potential of the basic data base. These data were collected between April and August 1980 from only those households completing both the background interview and the four biweekly telephone interviews. This supplemental information included more detailed data concerning an individual's personal habits, work habits, and workplace characteristics. More specifically, questions concerned:

1) The place of residence

- Type of heating/cooking fuel used
- Presence of air conditioning
- Residential history

2) The place of work

- Length of employment, salary, exposure to irritants, membership in a labor union, vacation/sick leave availability for individuals who were working either full-time or part-time at the time of the survey
- Occupation, nature of the job, length of employment, exposure to irritants for retired individuals

3) Income

- Proportion and source of income not related to jobs

4) General Health

- Height, weight, frequency of dieting
- Exercise patterns, time spent outdoors/watching TV
- Length of long term health problems
- Historical tobacco use

- Consumption of cured meats, sweets, salty snacks, and caffeine and the number of hot meals eaten per day
- Alcohol consumption (including frequency and type of alcohol consumed).

Data from both the basic survey and the supplemental survey were edited, coded, and merged into a single data file by GTI. The complete documentation for it is contained in Koontz (1981).

B. Survey Design

The sampling frame from which the 4160 households were drawn was taken from the 238 census tracts within the urbanized area of the St. Louis SMSA which were bounded by a network of continuous air quality monitoring stations. These 238 census tracts contained 432,162 households, or approximately 60 percent of those within the entire St. Louis SMSA. The 4160 households surveyed, then, represents somewhat less than 1 percent of the total in the sampling frame.

A stratified random sampling procedure was used to determine the exact choice of individual households to include in the survey. More specifically, the probability-proportional to size (PPS) technique was used in order to assure equal selection probabilities for all households. Equal selection probabilities, guarantee that the observations do not require weighting in any subsequent analysis. Counts of dwelling units by census tracts in 1970 were used as the basis for implementing the PPS technique. Obviously, due primarily to new home construction the actual dwelling unit count for 1978 would have differed, perhaps substantially from its 1970 counterpart. Consequently, the probabilities associated with each households inclusion in the sample are only approximately equal.

There are two additional problems with the sample to which attention also should be drawn. First, no specific attempts apparently were made to include observations from the institutionalized subpopulation. In other words, because the sampling design was based on dwelling unit counts, individuals subject to long term health care in nursing homes or hospitals may not have been adequately represented. To illustrate the impact of this problem, incidence of chronic conditions in the population of the United States can be compared to incidence in the original sample. Statistics compiled by the U.S. Department of Health, Education, and Welfare, National Center for Health Statistics (1973) indicate prevalence of chronic bronchitis, emphysema, and asthma (with or without hay fever) over the entire population which can be compared directly to the sample. Table 1 shows this comparison. As is evident, chronic illness incidence in the St. Louis health survey appears to be biased downward relative to national averages.

Second, of the 4160 households in the original sample, 1097 (26.4 percent) did not, for various reasons, either complete the Individual Background Interview or provide the diary data requested or both. For these individuals, only a portion of the information requested is

TABLE 1

INCIDENCE OF SELECTED DISEASES

	INCIDENCE PER 1,000 PERSONS	
	St. Louis Survey	National Survey
Emphysema	5.1	6.6
Bronchitis, chronic	3.8	32.7
Asthma	12.7	30.2

available. Also, for a household *to* be eligible for the supplemental or follow-up interview that household must have completed the initial phase. Of those eligible (3063), 84.7 percent then completed the follow-up interview; thus, there were 2594 households providing an entire data record. The major reasons for non-response or incomplete response during the initial portions of the survey were outright refusal to participate and relocation outside the St. Louis area. Corresponding primary reasons for non-response during the follow-up portion were outright refusal to participate and failure on the part of the interviewer to locate or contact.

Despite these difficulties, the sample information would appear to have three redeeming features. The first and most obvious is the care that was used in collecting the acute and chronic illness data. The illness classification scheme referred to earlier is very detailed; consequently users of the St. Louis data have a great deal of information concerning the respondent's chronic medical problems. Moreover, the diary type data reflecting acute illness is potentially useful particularly since they were recorded day-by-day rather than on the basis of recall by respondents. Second, data were collected for each respondent on a broad range of variables that are potentially useful predictions of illness patterns. The exact specifications for these data are described by Koontz; however, the availability of both current and historical measures concerning each respondent's income, education, smoking, exercise, exposures to on-the-job hazards and indoor air pollutants, leisure time activities, and diet is worth mentioning. Additional details concerning certain of these data are given in Chapter 6 of this report in which the empirical results are presented. Third, the data set also contains comprehensive information concerning the physical locations of the respondent's residence, employment, and other activities. Those data are of critical importance in matching air pollution exposures to the individuals surveyed, The air pollution exposure measurements are discussed in the Section 3 to follow and the matching procedure is described in Chapter 6.

3. St. Louis Air Quality Data

Air quality data are available from four sources for the St. Louis area: (1) the EPA financed Regional Air Pollution Study (RAPS), (2) the county of St. Louis, (3) the city of St. Louis, and (4) the Illinois Environmental Protection Agency. As previously indicated, the RAPS had been concluded prior to the time the St. Louis health data were collected. However, the air quality data based upon daily averages obtained from RAPS appear to be of substantially better quality as compared with those from the other three monitoring systems. As a consequence, they are used exclusively in this study in spite of the unfortunate time sequencing problem. In fact, Chapter 5, which presents a detailed comparison of all four air monitoring systems, concludes that the three locally operated networks simply do not provide daily data that are accurate to a useful degree of approximation. This conclusion implies that health-air pollution relationships estimated by matching the daily diary data with daily air quality readings from one of the three local monitoring systems are to be viewed with considerable suspicion. In fact, no such relations are estimated in this report and the daily diary data are not used. However, if local readings were averaged over a longer time interval, say a year, their correspondence to those obtained from the RAPS system are considerably closer. Thus, the implicit condemnation of the quality of the readings from the three local monitoring networks applies only when those data are used in daily average form.

A possible extension of the analysis presented in Chapter 6 would involve making comparisons between the estimated health effects of air pollutants by holding the regression specification constant and varying only the source of the air quality data. In such an analysis, the air quality data would be obtained from long term averages of readings from stations in each of the four monitoring systems. Due to the expense of matching the pollution exposures to the individuals surveyed and to the fact that the results would provide only a sidelight to the present study, the extension is not pursued. In Chapter 6, only the RAPS data are utilized, and as a consequence, the remainder of this section provides an overview of the data produced by the RAPS together with a correlation analysis designed to highlight certain features of importance.

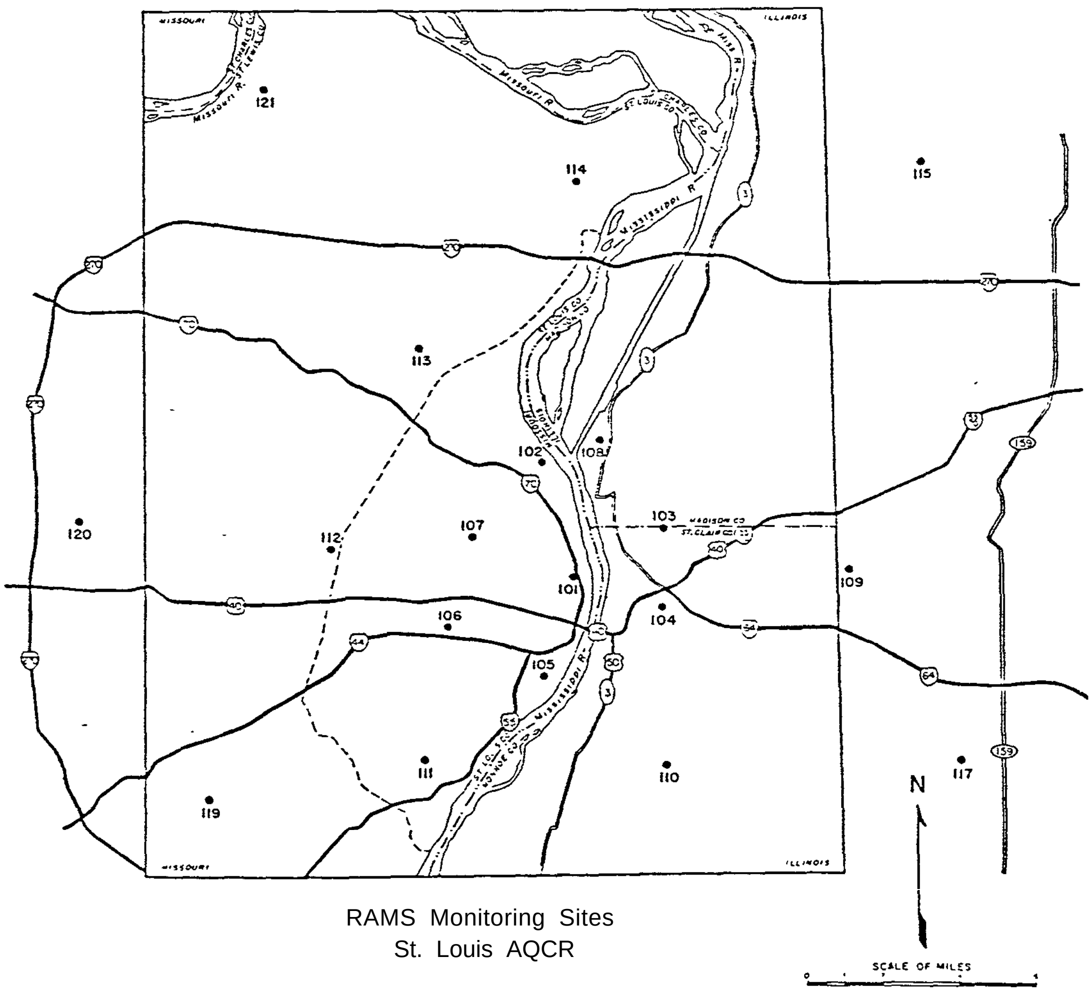
A. Background

Between the years 1974 and 1977, the Environmental Science Research Laboratory of the U.S. Environmental Protection Agency contracted with the Air Monitoring Center of Rockwell International to set up and operate an extensive monitoring system for meteorological and pollutant variables in the St. Louis, MO-IL air shed. This network, called the Regional Air Monitoring System (RAMS) was part of a larger Regional Air Pollution Study (RAPS) investigating many facets of the effects of emitted air pollutants on the scale of an entire Air Quality Control Region (AQCR). In addition to studies directly supplementing the RAMS surface network by helicopter and radiosonde measurements, RAPS included additional endeavors such as air-parcel trajectory studies extensive point source emission inventories, and analysis of micro-amounts of material in suspended particulates. The RAMS network was designed to provide state-of-the-art measurement and monitoring mechanisms.

The actual RAMS network consisted of 25 stations arranged in very roughly laid out concentric circles from a central urban station at radii 5, 11, 20, and 44 km (see Figure 1). The network was designed to generate an accurate and retrievable data base for all criteria and certain selected non-criteria pollutants to be used in air quality simulation models. Each station included pollutant analyzers, meteorological sensors, and test/control systems. Not every station collected data on all pollutants measured by the RAMS system. Table 2 lists the distribution of pollutant measurements by station. Table 3 displays the equipment used and the variables measured by the instruments.

One of the characteristics which distinguished the RAMS system from other monitoring networks existing in the St. Louis AQCR is the extensive attention paid to calibration and quality control. This is important since available instrumentation for gaseous pollutant measurements seem to manifest a tradeoff between stability and reliability of measurement and sensitivity of response to ambient changes and to low concentration levels. Since the focus of the RAMS network was on a complete concentration record, as evidenced by the production of complete records on minute intervals (see below), the instrument choice in the RAMS network tended to fall on the side of sensitivity and rapidity of response time which necessitated a comprehensive set of calibration and maintenance procedures. Measurements at the level of tenths and hundreths of parts per million (ppm) require sensitive instruments which are notoriously subject to internal drift and instability. The gaseous pollutant analyzers were automatically calibrated daily between the hours of 2000 and 2400 C.S.T. by an operating sub-system of the central computer which collected the data. Each gaseous pollutant measurement except hydrogen sulfide was so calibrated. Calibration was performed by a zero and one upscale point in the normal operating range of the instrument. If the instrument could change ranges, calibration was performed on the low range. Zero levels were obtained by introducing zero air into the calibration manifold. Calibrated source concentrations for the upscale point were diluted with air scrubbed of water and all pollutants and then introduced into the calibration manifold. Multipoint calibration was automatically performed at 10 week intervals. The hi-vol particulate samples were checked every 6 months, the dichotomous samplers were checked periodically with a flow meter calibrated at Lawrence Berkeley Labs. Technical details of these procedures can be found on pages 33-42 of the "Documentation of the Regional Air Pollution Study . . . ." cited below. Extensive preventive maintenance procedures also were performed on the RAMS hardware. In addition, quality audits were performed independently of RAMS operating, personnel. Table 4 is a reproduction of the summary of audit results on the RAMS network. Despite the apparently high average measurement errors and the wide range of errors encountered, the RAMS network is still considered to be one of the most reliable monitoring systems ever put together. The general conclusions of the audit procedures involving pollutant measurements can be paraphrased into the following list: (Documentation, p. 55).

1) Given proper calibration and maintenance procedures, most of the gaseous pollutants measurements were reasonably accurate.



RAMS Monitoring Sites
St. Louis AQCR

Figure 1

TABLE 2

RAMS REMOTE STATIONS INSTRUMENT DISTRIBUTION

	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125
O_3 - Monitor Labs 8410	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NO - NO_X Monitor Labs 8440	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CO - CH_4 THC Beckman 6800	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TS - SO_2 - H_2S Tracor 270HA	X		X	X	X	X							X	X	X	X				X	X	X			
TS - Meloy SZ 185		X					X		X	X	X	X					X	X	X				X	X	
Visibility - MRJ 1561		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Wind Speed - MRI 1022 S		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Wind Direction - MRI 1022D		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Temperature - MRI 840-1		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Den Point - Cambridge 880	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Temp. Gradient - MRI 840-2	X	X		X	X	X	X		X		X	X	X									X	X		
Barometer - MRJ 751/YSI 2014	X								X			X										X	X	X	
Solar Radiation (Eppley) Pyranometer			X	X				X						X				X				X			
Solar Radiation (Eppley) Pyrheliometer			X					X						X				X				X			
Solar Radiation (Eppley) Pyrogeometer			X					X						X				X				X			
Turbulence - R. M. Young 27002					X		X		X		X		X												
Gas Bags - Xonics	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Hi - Vol, Sierra 305			X		X	X		X				X			X			X		X		X			
LBL Dichotomous Sampler			X		X	X		X				X			X			X		X		X		X	
10 Meter Tower								X		X				X	X	X	X	X				X			
30 Meter Tower	X	X	X	X	X	X	X		X		X	X	X						X	X		X	X	X	

TABLE 3

INSTRUMENTATION USED IN POLLUTANT DATA COLLECTION

POLLUTANT	RAMS
Ozone	Monitor Labs 8410A chemiluminescent analyzer, Range: O-.20 ppm or O-.5 ppm, span value: min det: .005 ppm, ht: 4 meters
Oxides of Nitrogen	Monitor Labs 8440 chemiluminescent analyzer. NO, NO_x continuously - NO_2 by differencing Range: O-.50 ppm Span: .10 ppm Min det: .005 ppm ht: 4 meters
Hydrocarbons, carbon monoxide	Beckman Instrument, Model 6800 gas chromatograph, Ranges: CO: 0-10 or C-50 ppm ht: 4 meters
Sulfur dioxide & total sulfur	Tracor, Inc., Model 270 HA chemiluminescent analyzer. Total sulfur SO_2 simultaneous ranges 0-.2 ppm, O-1.0 ppm. Hydrogen sulfide: simultaneous ranges: O-.1 ppm, O-1.0 ppm. Min det: .005 ppm ht: 4 meters
Total Sulfur	Meloy Labs. Model SA-185 chemiluminescent analyzer range automatically selected: O-.2 ppm or O-1.0 ppm. Min det: .005 ppm ht: 4 meters
Wind speed	Meteorology Research, Inc. Model 10225 3-cup anemometer: 10 or 30 meter ht. range: .22-22.35 M/S 1 percent accuracy
Wind Direction	Meteorology Research, Model 1022D wind vane 10 or 30 meters. Range: 0-540° threshold: .3. Damping ratio: .4 at 10° angle
Temperature	Meteorology Research Model 840-1 dual thermistor resistor network: ht: 5 meters. Range: -20° C - +50° C
Barometric Pressure	Meteorology Research, 751/YST. Model 2014 transducer. ht: 2 meters Range: 27.0-31.5 inches (947-108Omb)
Solar Radiation	Eppley Labs precision spectral pyranometer, normal incidence pyreheliometer: ometer and pyrgeometer. 5 meters. Range: O-4 cal cm^2/min
Gas Bags	Xonic Inc. bag sampler, 100 liter teflon & tedlar bags 4 meters - ht flow rate: O-1200 cc/min.
T.S.P.'s	Sierra Instruments, Model 305. High vol. sampler. 20 x 25 cm. glass fiber filter - flow rate .02 m^3/sec. - by model 320 flow controller .4 meters
TSP's Fractionated	Lawrence Berkley Labs, dichotomous air sampler. Two size ranges, greater than and less than 2 micrometers

TABLE 4

SUMMARY OF AUDIT RESULTS

	Parameter Measured	Method	Average Error Found in Field Stations Calibration (Computed as slope error)	Range of Errors for the 8 Stations Audited
1.	Nitric Oxide	Chemiluminescence	12.5%	-5.8% to +29.2%
2.	Nitrogen Dioxide	Chemiluminescence	11.7%	-6.7% to +29.3%
3.	Total Oxides of Nitrogen	Chemiluminescence	12.3%	-5.7% to +27.4%
4.	Sulfur Dioxide	Gas Chromatograph and Flame Photometric	34.8%	-55.2% to -5.3%
5.	Hydrogen Sulfide	Gas Chromatograph		
6.	Total Sulfur	Gas Chromatograph		
7.	Ozone	Chemiluminescence	15.6%	-37.9% to +14.8%
8.	Total Hydrocarbons	Gas Chromatograph	12.8%	-23.9% to -3.6%
9.	Methane	Gas Chromatograph	22.1%	-31.3% to -10.5%
10.	Carbon Monoxide	Gas Chromatograph	17.2%	-32.0% to -1.5%
11.	Nitric Oxide Cylinder Concentration	HSL Calibrator-CPT	24.4%	+49.1% to +6.6%
12.	Permation Tube Water Temperature	Thermistor	0.4°C	-0.7°C to -0.3°C
13.	Dew Point	Thermistor	1.8°C	-2.3°C to +5°C
14.	Ambient Temperature	Thermistor	0.6°C	-1.6°C to +1.1°C
15.	NO_2 Converter Efficiency	15 of 16 tested 1 of 16 tested	greater than 90% efficiency 82% efficiency	

2) Ambient carbon monoxide levels less than 2 ppm were consistently measured low network-wide. This was because the Beckman 6800 analyzer had a breakthrough CO concentration for measurement of .3186 ppm. The actual minimum value was "not consumed by the over-concentrated stripper column." (Documentation, p. 67). The understated error decreases as the span pt. is approached.

3) The sulfur analyzers considerably improved in the later part of network operation, after 1975.

4) Details of the audit results conducted throughout RAMS' operation can be found in publication listed on p. 57 of "Documentation . . . ."

Data were collected for all variables except the high volume gas bag and automatic dichotomous samples on a minute by minute basis except for automatic calibration periods. Each station included a mini-computer on the premises which fed to 2 central computer data management system. Back-up storage was included at the RAMS site. The minute values represent averages over 120 1/2 second readings. A complete data record was produced every minute and the high volume samples obtained a 24-hour sample every three days. The gas bag samples took a sample on an as-required basis. The automatic dichotomous samples collected a sample every 2 to 12 hours depending on study requirements. The body of the RAMS data base dates between January 1, 1975 and March 31, 1977. Table 5 gives the exact dates of operation for each of the RAMS network stations.

For the purposes of this health study, not every RAMS station was utilized. In particular, six of the stations, those numbered 116, 118 and 122-125 on Figure 1, were completely outside the health survey study area. Each respondent's reported home location always was closer to one of the other 19 stations. The measurements from those stations were those utilized in assigning air pollution exposures to the survey respondents. Table 6 gives a characterization of the extent of missing data in the data base. Cells with an asterisk indicate variables not measured by a particular station, so that a value of 438 or 439 is expected. Also shown in Table 6 are the mean days with no data across stations by variable. This is computed using only the 19 stations in the health study, and only those stations which were supposed to be measuring a parameter. Such an aggregate view of the missing data characteristics is perhaps only relevant when judging the quality of the data base in its use studying chronic health effects. System-wide, equipment measuring ozone and nitric oxide seemed to be particularly reliable, with the equipment measuring hydrogen sulfide being particularly problematical. It is somewhat puzzling that although one instrument, the Monitor Labs 8440, was responsible for measurements of nitric oxide, nitrogen dioxide, and oxides of nitrogen; the mean days missing over the last two measurements was more than twice that of the first.

B. A Correlation Analysis of the Air Quality Data

The correlation analysis of the RAMS air quality data is designed

TABLE 5

OPERATION DATES OF RAMS STATIONS

OPERATION DATES:

STATION	START	STOP
101	8/15/74	3/31/77
102	6/28/74	3/31/77
103	6/24/74	3/31/77
104	8/20/74	6/30/77
105	8/02/74	3/31/77
106	4/22/74	6/30/77
107	8/28/74	6/30/77
108	8/02/74	3/31/77
109	6/19/74	3/31/77
110	8/21/74	3/31/77
111	8/26/74	6/30/77
113	6/24/74	3/31/77
114	8/20/74	3/31/77
115	6/02/74	6/30/77
116	7/21/74	3/31/77
117	7/09/74	3/31/77
118	7/26/74	3/31/77
119	9/04/74	3/31/77
120	8/27/74	3/31/77
121	7/26/74	6/30/77
122	8/09/74	3/31/77
123	8/07/74	2/12/77
124	7/24/74	2/12/77
125	7/14/74	6/30/77

TABLE 6

DAYS WITH NO DATA

STN	TEMP	BARO	OZONE	CRBMON	METH	HYDRO	NITOX	NITDIO	OXNIT	SULFUR	HYSULF	SULDIO
1	15	98	19	90	45	73	26	119	126	43	14	30
2	0	439*	1	20	28	29	6	17	19	55	439*	439*
3	1	439*	11	29	64	54	22	63	65	15	26	13
4	2	439*	15	53	76	74	178	27	24	22	73	22
5	1	439*	8	83	54	74	7	10	10	26	52	25
6	2	439*	18	30	65	47	18	26	21	117	162	64
7	0	439*	5	40	59	73	4	29	26	66	439*	438*
8	0	439*	6	22	19	78	10	12	15	42	114	37
9	2	0	19	71	25	15	62	74	48	82	439*	438*
10	0	439*	12	32	57	47	18	55	49	46	438*	439*
11	11	439*	11	65	88	81	11	102	102	60	439*	438*
12	13	11	11	77	55	172	14	52	49	70	438*	439*
13	0	439*	7	88	84	76	12	30	23	22	140	21
14	1	439*	18	93	53	66	15	25	20	20	70	29
15	4	439*	20	96	71	66	15	18	18	51	352	46
**16	9	439*	43	106	98	87	31	39	36	53	77	50
17	7	439*	21	44	49	52	50	03	48	20	439*	438*
**18	9	439*	23	12	24	22	25	27	27	55	438*	439*
19	1	439*	17	19	66	40	20	59	54	59	439*	438*
20	51	439*	37	70	68	70	26	40	36	58	116	63
21	0	439*	17	80	33	56	15	42	37	40	135	27
**22	1	3	24	52	93	65	22	26	25	30	175	22
**23	2	2	70	56	70	70	26	34	29	71	439*	438*
**24	72	2	53	79	75	72	21	45	46	24	438*	439
**21	12	85	47	110	112	146	36	45	37	53	439*	438*
Mean days w/o data	5.8		14.4	58.0	55.7	65.4	19.4	45.4	41.6	48.1	114	34.3

*: indicates station not equipped to measure this variable
**: indicates station not used in health-impact estimation

to obtain information of use in specifying the regression models estimated in Chapter 6. Two types of correlations are calculated: (1) for a given aerometric measure between stations and (2) for different aerometric measures at a given station. The main interest in making these calculations lies in discerning which readings tend to be highly correlated, thereby duplicating exposure information. More specifically, the first type of correlation coefficient shows the extent to which individuals living at different locations in St. Louis are subject to different exposure patterns. The second type of correlation coefficient, then, shows which air quality measures have 2 high linear association. That knowledge could help to avoid a multicollinearity problem in later empirical work and to define better proxies for missing variables. For the following correlation estimates, only data from the times 0600 to 2000 were used. As mentioned before, calibrations were performed between 2000 and 2400 daily and from 2400 to 0600 the bulk of the population is inactive. All coefficients cited are Pearson correlation coefficients, all test of significance are two-tailed.

1) Correlation Between Stations for Given Measures

Beginning with temperature, as would be expected, all stations are highly correlated, for the most part at values of .98 and up. The outstanding exception is Station 120 which appears to consistently read lower temperatures than the rest of the stations in the network. For this one station, correlation with other stations are in the .60-.75 range.

Ozone measurements also stand out as implying a relatively homogenous exposure field over the entire region. There are no uncomputable correlations between stations, and no negative correlations. There also are no insignificant relationships between stations, the only pollutant for which this was true. The Pearson coefficients range from a maximum of .8988 between Stations 102 and 111 to a minimum of .3317 between 109 and 115. Stations 102 and 111 are both located in St. Louis city along the Mississippi River although 102 is in the north part of town and 111 is at the southern end of the city limits. Both 109 and 115 are in Illinois at the eastern edge of the study region with 109 being adjacent to East St. Louis and 115 being approximately 20 miles north adjacent to Southern Illinois University at Edwardsville. Despite these comparatively high correlations, however, there was substantial variation in the mean values of the ozone observations between stations. The lowest mean reading, for Station 104 was about 54 percent of the highest mean reading, which occurred at Station 121.

Carbon monoxide revealed wide variation in correlation coefficients between stations. The maximum coefficient was between 120 and 101; .8926 with the minimum being between 105 and 114; .0005. The exposure field, thus, appears to vary considerably for carbon monoxide. There are no negative correlations or uncomputable coefficients. Out of a potential 171 relationships in the exposure field, the null hypothesis of a discontinuity (e.g., no relationship) in the exposure field along a particular gradient between two stations could not be rejected at a 5 percent level for only 18 cases. All low correlations (insignificant coefficients) were geographically dispersed. Stations 101 and 120, although approximately 15 miles from each other (east to west), are both enclosed by the intersection of major transportation arteries. Stations 105 and 114 are widely separated, 105 being downtown next to the intersection of I-55 and I-44, with 114 being in a rural area north of St. Louis near the intersection of the Missouri and Mississippi Rivers. The picture formed is one of sub-regions with a uniform exposure field, each sub-region still well connected to other sub-regions rather than the whole region being relatively homogeneous as with ozone.

The methane field exhibits, in general, a much weaker set of relationships among stations than all other pollutants except sulfur dioxide and hydrogen sulfide (see below). The maximum is between stations 101 and 102 with a coefficient of .3983. Of the 171 relationships between stations, 23 are negative, and in approximately 40 cases the null hypothesis of an exposure field discontinuity is accepted at the 10 percent level. The lowest correlation coefficient in this set was -.0723; the lowest positive coefficient was .0025. Both of those were not significantly different from zero at the 10 percent level. The pattern of relationships, as well as appearing weak, also appears to be quite complicated. For example, the methane readings from Stations 106 and 107, both located in St. Louis about three miles apart, arc basically uncorrelated. Station 106 is sandwiched quite closely between two freeways, while 107 is not. However, Station 108, which is across the Mississippi River in Illinois about seven miles away has 2 significant relationship with Station 106 at the 5 percent level. Station 108 is located in an industrial area subject to a fair amount of ship, barge, and rail traffic. For the most part, however, widely dispersed stations exhibit low correlations. Assuming no measurement problems, the picture which emerges in a very localized pollutant exposure field, not well connected into one large urban field, heavily dependent on specific site characteristics.

The total hydrocarbon field is more akin to the carbon monoxide field than to the methane field. The positive range is from a maximum of .6268 between Stations 102 and 107 to a minimum of .0338 between 115 and 105. There is only one negative correlation, between 119 and 108, but that coefficient was not significantly different from zero at the 5 percent level. By way of contrast to methane, only 12 out of 171 Pearson correlation coefficients insignificantly different from zero, 141 relationships exhibited a coefficient greater than .2 (significant at the 1 percent level), showing a well-connected relatively homogenous field. Insignificant relationships appear well-behaved in terns of expected geographical dispersion.

The oxides of nitrogen variables all present a similar exposure field image among one another. The nitric oxide and total oxides of nitrogen coefficients, which are based on direct readings; are particularly similar. The nitrogen dioxide correlation matrix, although very similar, is not as directly comparable to the former as the former are to each other. For nitric oxide, the coefficient range is between .7986 between Stations 107 and 111, and .0959 between Stations 106 and 117. At a 10 percent level, the null hypothesis of no relationship can be rejected for all coefficients. There were no negative correlations. Most of the coefficients are in the .4 to .7 range.

The total oxides of nitrogen correlation matrix shows a range of .7493 between Stations 114 and 108 down to .0547 between 105 and 121. Relationships are overwhelmingly significant except for two, the minimum cited above and .0650 between Stations 106 and 109. Both of these coefficients came from stations that were quite distant from each other. Although the total oxides of nitrogen and nitric oxide fields appear similar in structure, they are not identical. For example, some relationships between stations over the two pollutants are almost identical others are not. Between Stations 108 and 101, the nitric oxide correlation coefficient is .6822, the oxides of nitrogen coefficient .6911. However, between Stations 106 and 110, the nitric oxide correlation is .6116, the oxides of nitrogen correlation is .2739.

The nitrogen dioxide matrix is obtained from measurements derived by differencing the nitric oxide and oxides of nitrogen readings. The positive range, similar to the above, is from a maximum of .6210 between Stations 114 and 108 down to .0106 between Stations 117 and 106. The maximum is between the same two stations as the total oxides of nitrogen maximum, the minimum between the same two stations as the nitric oxide minimum. There were five relationships with negative coefficients, of which one could be considered non-zero, between Stations 121 and 110, which are widely dispersed. In general, the relationships between stations are significant but of lower magnitude than the direct measurements. Only further study can determine whether this situation is due to the measurement method for nitrogen dioxide or whether there is a qualitative difference between the exposure field for nitrogen dioxide and either the fields of nitric oxide or total oxides of nitrogen. In any case, one obtains an image of a well-diffused pollutant class for oxides of nitrogen, not as homogenous as ozone, but certainly more homogenous than the hydrocarbon group.

Characteristics change dramatically when the sulfurous group of pollutants are considered. Turning first to the total sulfur readings, the positive coefficients range from .4877, between Stations 102 and 111, down to .0028 between Stations 101 and 105. There are many negative coefficients, representing relationships between 15 sets of stations. Among these negative coefficients, the null hypothesis of no relationship was never rejected at the 5 percent level. Among the 171 relationships, approximately 65 involved coefficients where the null hypothesis of no relationship could not be rejected at the 5 percent level. Total sulfur was measured at all stations, but not by the same instrument at every location. Two instruments were used to cover the total sulfur field. Whether this had an impact on consistency of measurement between stations is not known, although the structure of the coefficient matrix is similar to that of the related pollutants sulfur dioxide and hydrogen sulfide, which were both generated by a single instrument.

Hydrogen sulfide measurements generate the most unusual pattern of correlations of all the inter-station readings. Measurement equipment was missing at several stations, although there were no unexpected uncomputable correlations. Among computable correlations, 68 are negative and 51 are positive. The positive coefficients range from .6407 between Stations 115 and 104 down to .0029 between Stations 114 and 103. The negative values range from -.0043 between Stations 105 and 108 down to -.1134 between Stations 121 and 113. Overall, these correlations exhibit low significance; only seven relationships could be characterized as rejecting the null hypothesis. The maximum coefficient cited above is a true outlier. The two stations involved are widely geographically dispersed, making for some suspicion as to the validity of the coefficient. The related coefficients between 115 and 104 for total sulfur and sulfur dioxide are .1151 and .1277, respectively. If there is one exposure field generated by the RAMS system of which to be suspicious, the hydrogen sulfide field would be a prime candidate.

Finally, sulfur dioxide's relationship matrix is similar in structure to hydrogen sulfide's. There were no unexpected uncomputable correlations, with the total number of relationships computed matching that of hydrogen sulfide's field. There are 93 positive and 16 negative computed relationships. The positive range was from .2662 between Stations 114 and 115 down to .0008 between Stations 104 and 105. The negative range was from -.0017 between 119 and 140 to -.0479 between 121 and 108. Stations 104 and 105 are right across the river from each other in high density industrial and transport areas while 114 and 115 are in rural areas north of St. Louis across the river from each other, but further apart than 104 and 105. Stations 121 and 108 are quite widely separated, while 119 and 120 are fairly close together in what appear to be similar residential communities. Not much rhyme or reason can be made from the geographic characteristics of these extreme values. There are about double the significant relationships among sulfur dioxide measurements as compared with the hydrogen sulfide measurements; however, sulfur dioxide is still a very disconnected, heterogeneous exposure field. Among the sulfurous measurements, the exposure field can be treated as either extremely localized (the most localized of any pollutant class) or as unreliable. There is not enough information to differentiate rigorously between these possibilities.

2) Correlations Between Measures for Given Stations

Of greatest interest among the single station, between measure-estimates is the possible use of total sulfur as a proxy for hydrogen sulfide and/or sulfur dioxide, since the former was measured at every station, while the latter two were only measured at eleven out of the nineteen stations in the study zone. Between SO_2 and total sulfur, the average correlation over eleven cases was .77 with a standard deviation of .10. Two stations exhibited extremely high correlations between SO_2 and total sulfur: station 113: .9368, and station 101: .9136. Between total sulfur and hydrogen sulfide, over eleven stations, the average correlation was .33 with a standard derivation of .28. The range in this set was from

.0542 to .8396. Perhaps total sulfur can be used as a proxy for SO_2, however, this is probably not the case for hydrogen sulfide.

Another feature of the single station-between pollutant correlations is the preponderance of negative correlations between ozone and all other pollutant measurements. Many of these negative correlations were significant at least at the 5 percent level. Of the 156 ozone--other pollutant correlations by station, 131 were negative and 25 were positive. Station 113 had the highest incidence (6) of positive and positive significant correlations. The rest of the positive correlations were fairly widely distributed over stations and pollutants. Temperature was highly positively correlated with ozone, as might be expected. Mean correlation was .55 with a standard deviation of .09. The incidence of significant negative correlations (5 percent level) not involving barometric pressure, temperature, or ozone measurements in the relationship was very rare. There are only five: (1) Station 106 between SO_2 and methane, (2) Station 106 between CO and methane, (3) Station 110 between CO and methane, (4) Station 117 between sulfur and CO; and, (5) Station 120 between hydrogen sulfide and methane. In a very general sense, then, the data suggest that exposure to ozone and exposure to other pollutant groups are inversely related.

The data further suggest that total suspended particulates (TSP's) share this characteristic of being inversely related to other pollutant groups. Because of the nature of TSP measurement techniques, correlations between TSP's and other variables were performed differently than correlations between other pollutants. Of the ten stations taking TSP measurements, only eight operated throughout the study period. Of these, two took samples of six hours instead of twelve hours. TSP measurements consist of blowing atmospheric air through a filter for a specified period and measuring the accumulated particulate mass. For the six remaining stations, the twelve hour duration TSP measurement starting at noon was matched to the daily mean for ozone, total hydrocarbons, oxides of nitrogen, and total sulfur. A Pearson zero-order correlation coefficient matrix was then calculated using the small and large TSP measurements separately. Focusing on results for Station 108 suffices to illustrate the resulting pattern. At station 108, the correlation between small TSP particles (TSPS) and ozone was .1589, while the coefficient between large TSP particles (TSPL) and ozone was .1951. The correlation between total hydrocarbons and TSPS was -.0113, between total hydrocarbons and TSPL the correlation was -.2000. Between oxides of nitrogen and TSPS and TSPL, the coefficients were -.1288 and -.1602 respectively. For total sulfur the respective coefficients were .0690 and .0203. In other words the pattern can be described as a small but significant positive correlation between ozone and TSP with roughly equivalent negative correlation between TSP and the groups of hydrocarbons and oxides of nitrogen. Between TSP's and the sulfur group the correlations are weaker and of mixed sign. The pattern is somewhat more pronounced for large particles than for small particles.

Among the oxides of nitrogen group, there would perhaps be some interest in using nitric oxide as a proxy for NO_2, or total oxides of nitrogen, given the relatively lesser incidences of missing data as described by Table 6. Among stations in the study area, the mean correlation between oxides of nitrogen and nitric oxide was .77 with a standard derivation of .14. Between nitric oxide and NO_2 the mean correlation was .49 with a standard derivation of -16. Parenthetically, the mean correlation between NO_2 and oxides of nitrogen was .77 with a standard derivation of .11, almost identical to the nitric oxide, oxides of nitrogen correlation above. Unfortunately, oxides of nitrogen was not the variable with the substantially fewer missing values!

Among the hydrocarbon group, only methane and total hydrocarbons even approached being modestly correlated. Again, among study area stations, this calculation set had a mean of .70 with a standard deviation of .10 comparing favorably with other highly correlated sets. Carbon monoxide and methane, and carbon monoxide and total hydrocarbons, were consistently significantly related, but at much lower levels (less than .3 average). The existence of the "automobile effect" is evident by the average correlation of approximately .45 between total hydrocarbons and both nitric oxide and total oxides of nitrogen.

4. Summary

This chapter has provided a description of the health and air quality data to be used in empirically implementing the theoretical model presented in Chapter 3. That description focused on the types of variables measured as well as how the data were collected. The results of a correlation analysis performed on the air quality data obtained from the RAMS also were presented in order to assess the degree of association between: (1) measurements of the same pollutant at different locations and (2) measurements of different pollutants at the same locations. One key question not adequately addressed in this chapter, however, concerns the rationale for using air quality data from the RAMS system. Chapter 5 pursues this question together with the implications of choosing the RAMS data for the empirical estimates to be reported later.